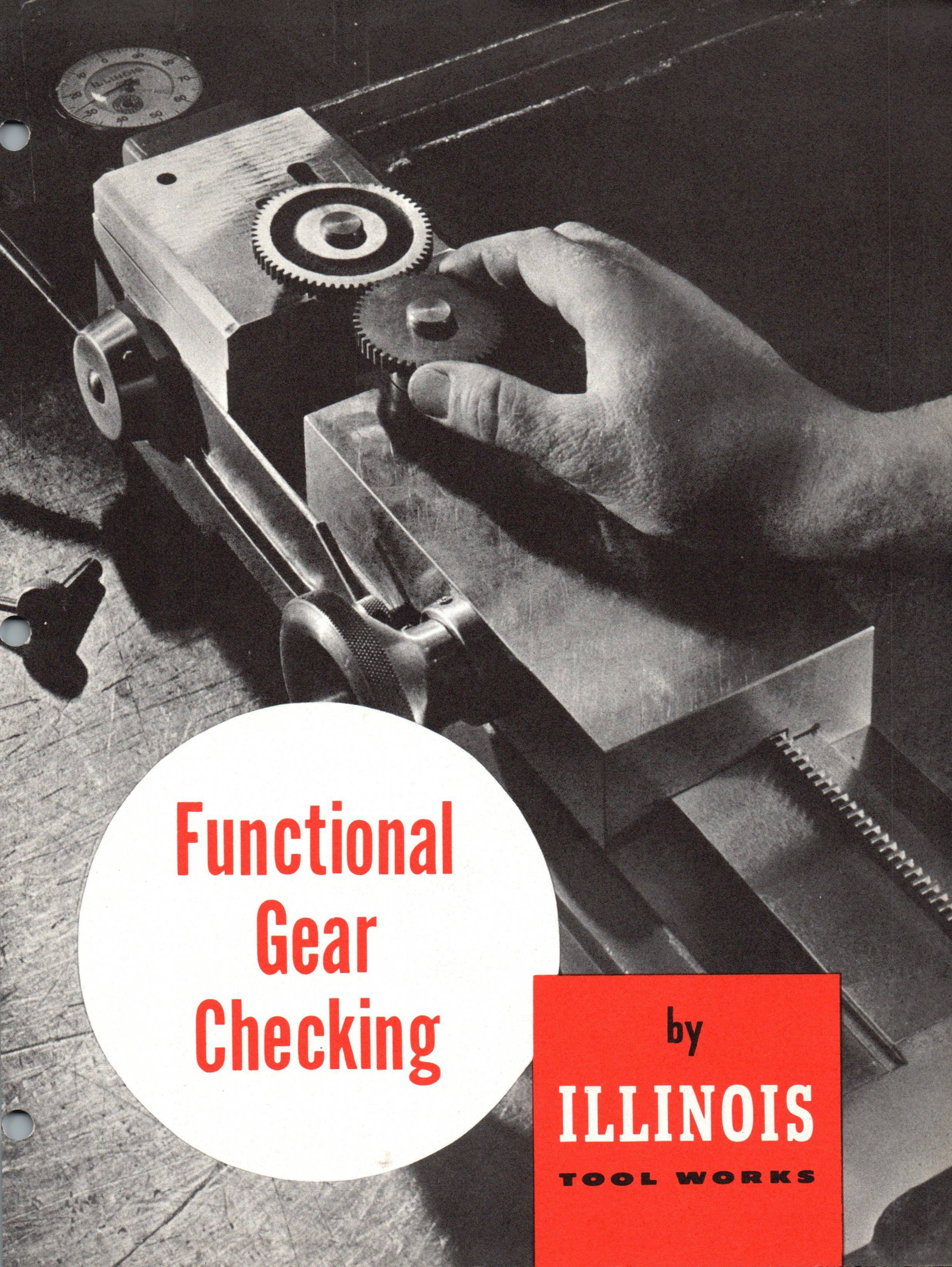
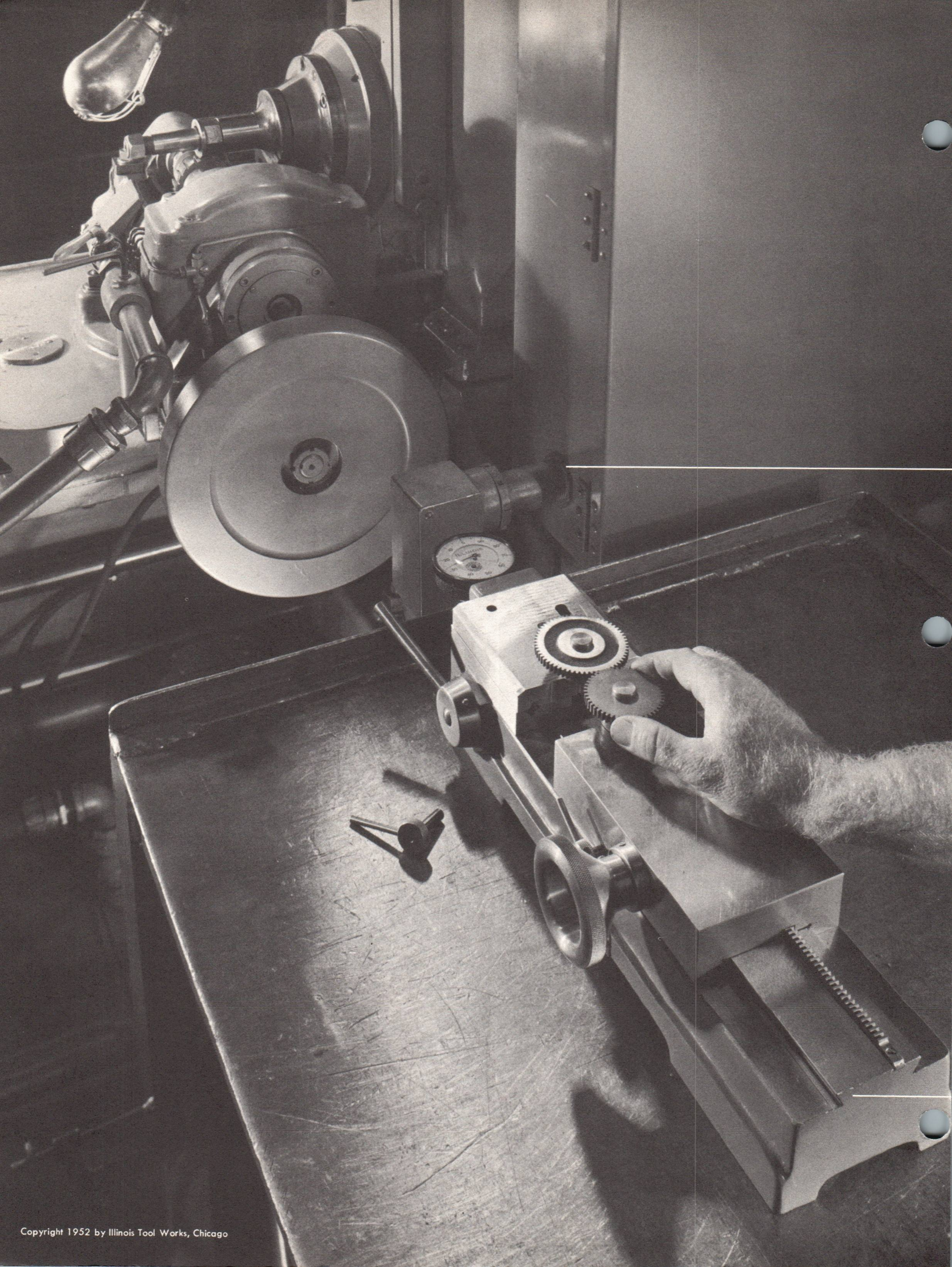


Functional Gear Checking

by

ILLINOIS

TOOL WORKS



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FUNCTIONAL GEAR CHECKING

BY ILLINOIS TOOL WORKS

The immediate purpose of gear inspection is assurance of a certain standard of accuracy and quality. In addition, gear checking also serves to control gear manufacturing processes in the most economical way, a complex process requiring the right combination of several different methods of inspection.

Basically, there are two distinct types of gear checking, functional and analytical. The first consists of testing gears by the way they roll or function; the second comprises the various methods which check the dimensional characteristics of a gear such as involute, spacing or lead. Illinois Tool Works has pioneered in the design and production of a complete line of inspection equipment for both of these basic types.

In the history of the development of modern gear checking, testing gears by the way they roll or function came first. Today, in the most up-to-date gear departments, the rolling fixtures and gear charters are still the policemen of the process. Simple rolling fixtures, using master gears and indicators, are placed among the hobbing, shaping and shav-

Figure 1. Illinois Tool Works gear rolling fixture placed beside hobbing machine.

ing machines to check the output of these machines constantly. The same kind of fixtures, sometimes combined with recording devices, are again found in the final inspection department. As universal machines, usually combined with recording, they are an important part of every gear laboratory. See Figure 1.

The basic construction of modern gears is fairly well standardized. Almost all parallel axis gears use the involute for the form of the teeth and they are either spur or helical gears. Similar generalizations can be made about worm gears and splines, but beyond these basic points all generalizations about gears must cease. Gears for the proverbial concrete mixers cannot be compared with those that serve in ships, automobiles or planes.

The question of whether or not to check a gear is directly tied in with the ultimate performance requirements for that gear. It is not correct to say that all gears should be checked, nor does this pamphlet, by its very existence, intend to leave that impression. Within certain wide limits, the performance of modern hobbing and shaping machines, together with their generating tools, is reliable. If the gears turned out by these machines are within all requirements for accuracy, they need not be checked at all, except, possibly, for size.

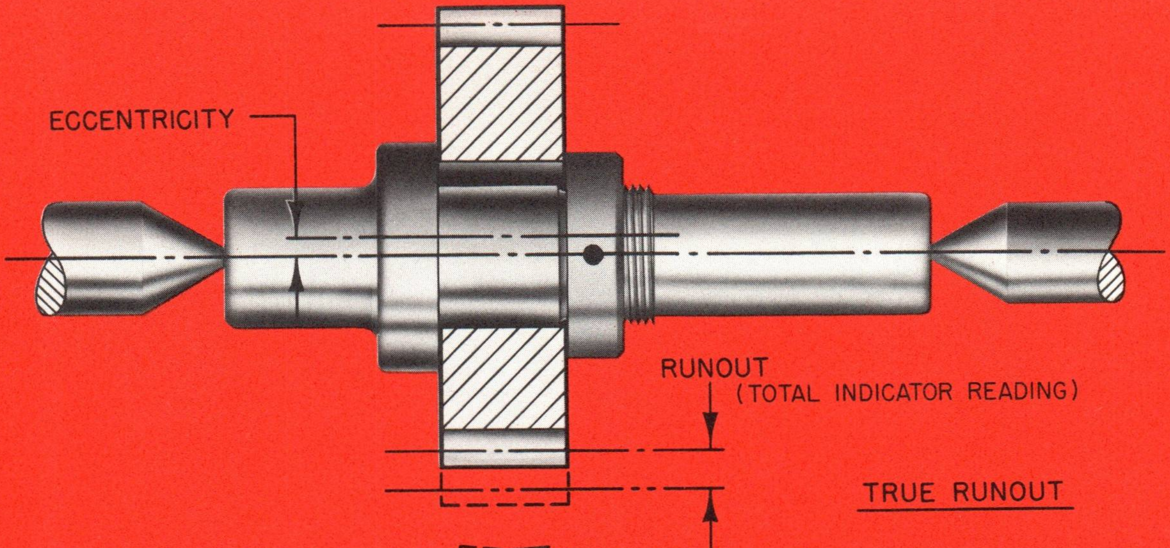
However, gears which are to give long, continuous service, run quietly and transmit great loads *must* be checked because it is accuracy which makes that performance possible. The uncontrolled output of gear generators does not assure gears of sufficient quality. To put it differently; if the accuracy of a gear is such that obtaining it required true running, precisely sharpened hobs and true running work arbors, then the gear itself will require checking.

One of the main reasons behind this statement is the fact that a lot of the imperfections that occur in a gear during the process of manufacture are additive. For instance, a side wobble, a heat treat distortion and a runout in the work arbor may all combine to produce a totally unacceptable gear. The same goes for a hob whose slight lead error may have been intensified by poor sharpening and then further aggravated by runout of the hob spindle (see Illinois Tool Works booklet on "The Right and Wrong of Modern Hob Sharpening.")

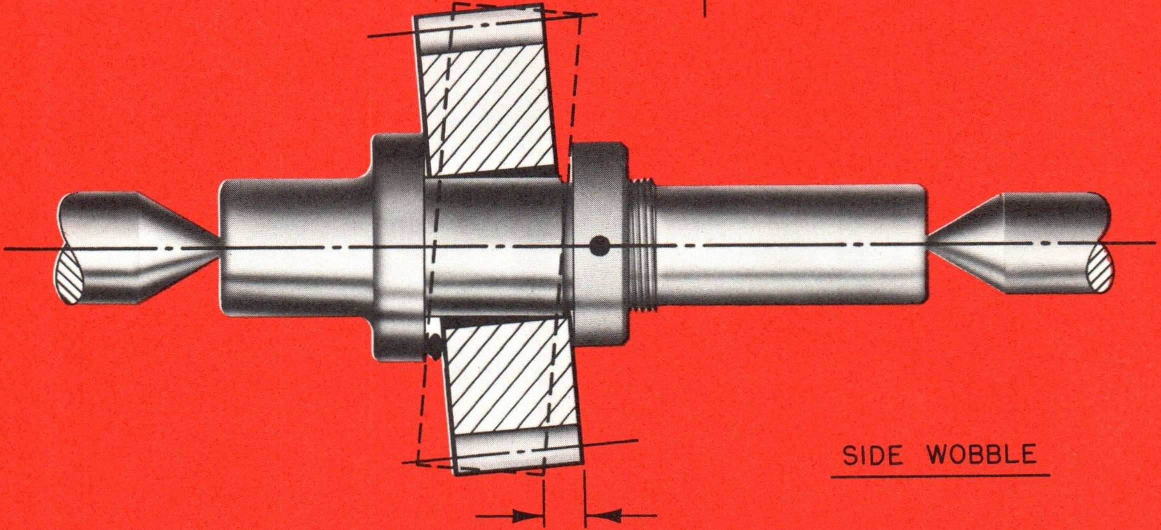
The ultimate accuracy of a gear is a complex combination of many factors. It is universally appreciated that accuracy of the holes in gear blanks is of major importance in controlling runout. Frequently overlooked, however, is the fact that side wobble is equally important. As a matter of fact, it is somewhat futile to differentiate between the two—side wobble is just another form of runout. In actual practice, the runout of gear blanks is some combination of the three types of runout shown in Figure 2.

Hobbing and shaping machines have their own complex interplay of inaccuracies in the various spindles, arbors and gears. These have a certain effect upon the gears produced. And to them must be added the inaccuracies of the generating tools—those that are inherent in the tool as well as those which have been induced by improper sharpening and mounting.

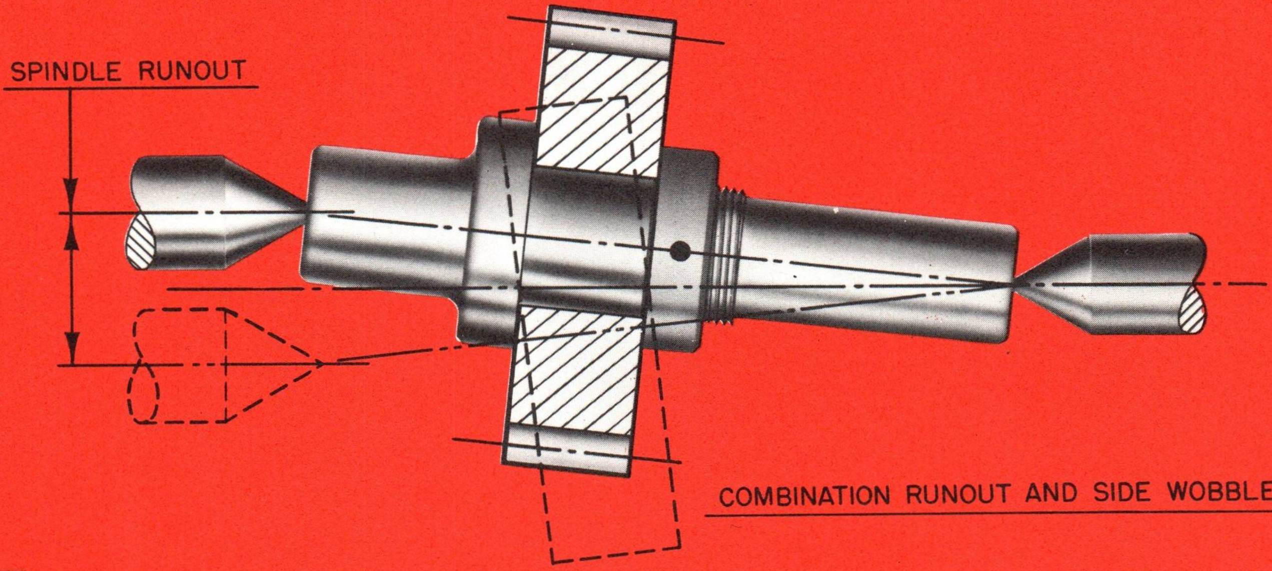
Figure 2. Types of runout.



TRUE RUNOUT



SIDE WOBBLE



COMBINATION RUNOUT AND SIDE WOBBLE

In the case of Illinois Tool Works hobs, the effect of the generating tools on the finished gears can be accurately predicted by means of the TOOL-GRAPH* Chart which accompanies every hob shipped. This chart is an electrically produced graph of final inspection results and shows those hob characteristics which affect gear accuracy quite clearly.

Other errors are the result of deflections in arbors and shafts under the strains of cutting, distortions due to heat treatment, dirt and chips on the locating surfaces. This list of possible causes of inaccuracies in gears is by no means complete, but enough of them have been mentioned to indicate *the amount of control* which must be exercised to produce fairly accurate gears.

In theory it might be possible to control the quality of gears by constantly checking all parts of the machines, tools, gear blanks and arbors, everything capable of causing error. But it would be a hopeless task, complicated by the fact that a lot of errors are additive. It would be necessary to maintain exceedingly close tolerances everywhere in order to keep their possible additions within limits.

It is far more expedient and economical to check the gears and trace any excessive errors back to their source. That is the *job of functional gear checking or checking gears by the way they roll or function.*

Inspecting *all* the details of a gear involves a whole series of checks—size, lead or straightness, involute, spacing and runout. A few gears, master gears for instance, are actually checked in this way. However, even the checking of master gears cannot truly be called 100% inspection. Gears usually have many teeth and to repeat the helical lead and involute check on every tooth would mean a considerable burden. Therefore, the most accurate gears, master gears, are checked for size, for runout and for spacing all around. They are further checked for lead and involute on a few scattered teeth and it is assumed that all other teeth will be alike. If true 100% inspection is neither economical nor necessary on master gears, it is certainly not warranted in the case of production gears, even though they might carry a "precision" label.

Gears are meant to transmit loads at constant angular velocities. The more constant the velocity, the smoother the transmission and the better the gears. Theoretically at least, constant angular velocity is the result of perfect involutes, tooth spacing and helical leads. Unfortunately, there are no such things as perfect involutes and tooth spacing and if there were, they would soon become quite imperfect due to deflections under load. Nevertheless, relatively smooth rotation is still the main criterion of a gear's quality. Since it can only be achieved by relatively true running gears with good involutes and spacing, it is certainly justifiable to check the smoothness of rotation of the gear without going into all the details of runout, spacing and involute. This means checking a gear by the way it functions.

In functional gear checking, gear rolling or gear charting, the gear to be checked is rotated with a master of known accuracy in intimate metal-to-metal contact. If involute, spacing, helical lead and

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*T.M. Reg. U.S. Pat. Off.

Figure 3. Illinois Tool Works gear rolling fixture for internal gears.

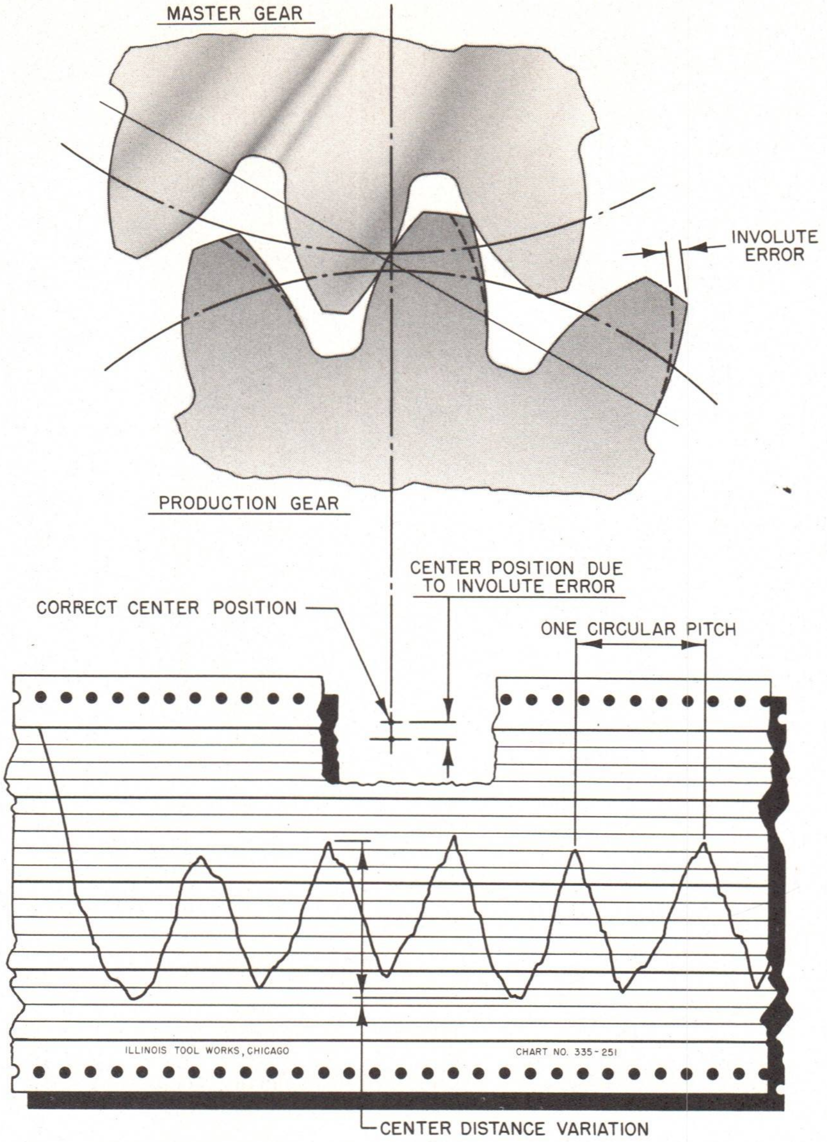
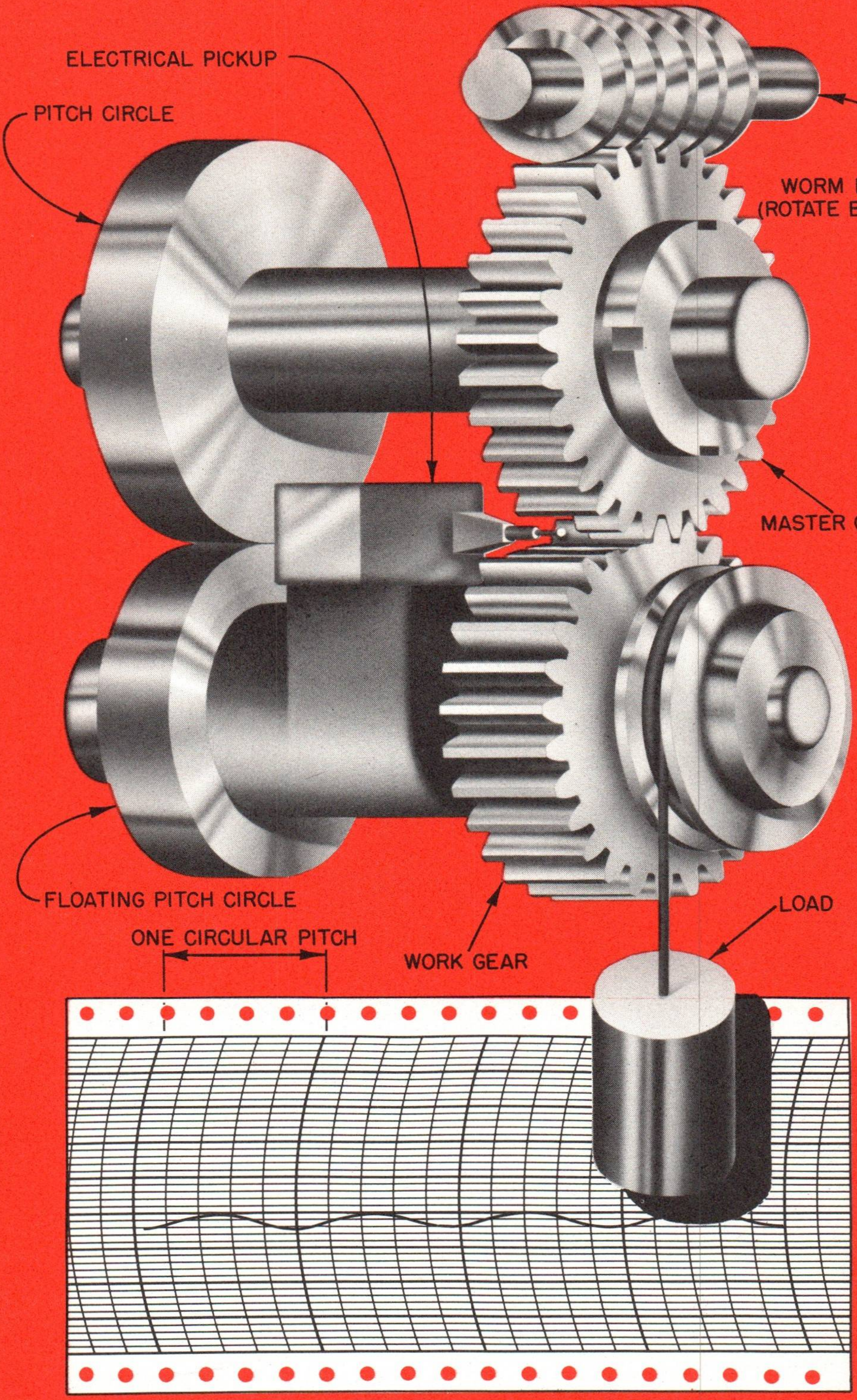


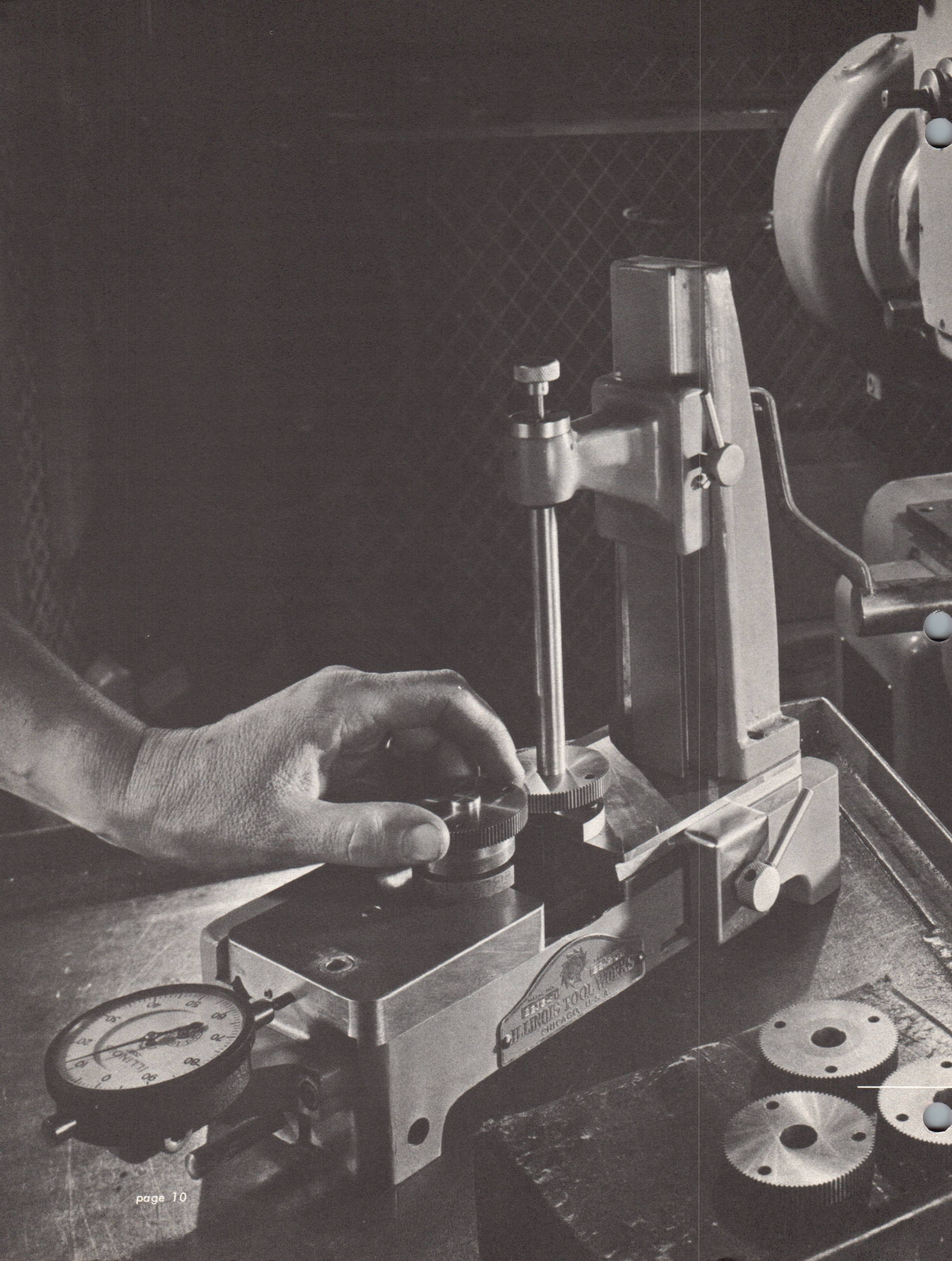
Figure 4. Center distance fluctuations due to involute error.

runout were perfect in both master and gear, the two would roll together at no variations in center distance. If, however, errors are present in any one of their elements, then the following will happen: size and runout of the gear will be reflected at their true value; involute, spacing and helical lead will show up on indicator or chart at a distorted but magnified ratio, depending upon the pressure angle. Errors in the master gear, regardless of their nature, merely confuse and subtract from the accuracy picture which is obtained of the gear.

Admittedly this rolling check is not truly functional because gears do not roll in metal-to-metal contact in operation. With the exception of some instrument gears, all gears are made with backlash, rotate at fixed center distance and contact on the driving side of the tooth. Furthermore, a true func-

Figure 5. Diagram of angular velocity test under load and chart.


ELECTRICAL PICKUP
PITCH CIRCLE
WORM DRIVE
(ROTATE BY HAND)
MASTER GEAR
FLOATING PITCH CIRCLE
LOAD
ONE CIRCULAR PITCH
WORK GEAR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tional check should reveal the errors as they result in variations in angular velocity.

Such a check can actually be made by an arrangement similar to that in Figure 5. It even permits testing gears under full load, partial load, or when idling and can check the combined effect of all errors, tooth deflections and intentional profile modifications as they affect the rotation of two gears. The check is reliable for a partial rotation of, say, 90°. Beyond that, runout conditions between the gears and pitch circles cause a drifting of the pattern which need not be a reflection upon the gears. However, this kind of a truly functional check does not indicate size and runout as clearly as metal-to-metal rolling does. Furthermore, it is not as simple, handy and easy to operate as the rolling fixture. It is strictly a laboratory method, only of interest to those manufacturers who want to check more deeply into the behavior of their gears.

While the rolling check is admittedly not a true functional check, it is the closest and by far the most economical approach to it. The measured variations in center distance may not be exactly proportional to the variations in angular velocity, but they do give a wonderful picture of the gear's quality. For what it may lack in some respects, gear rolling gives a correct measurement of size and runout. Beyond that, it gives an admittedly distorted but nevertheless indicative picture of the combined errors of involute, spacing and helical lead. If excessive, these errors should be analyzed on involute, lead and space checking machines. Actually this combination of functional and analytical checking has been found by industry to be the most economical way to avoid costly 100% inspection and yet assure a definite and consistent standard of quality.

It was pointed out earlier that the final accuracy of a gear is the combined result of the accuracy of the generating machines, the tools, arbors, gear

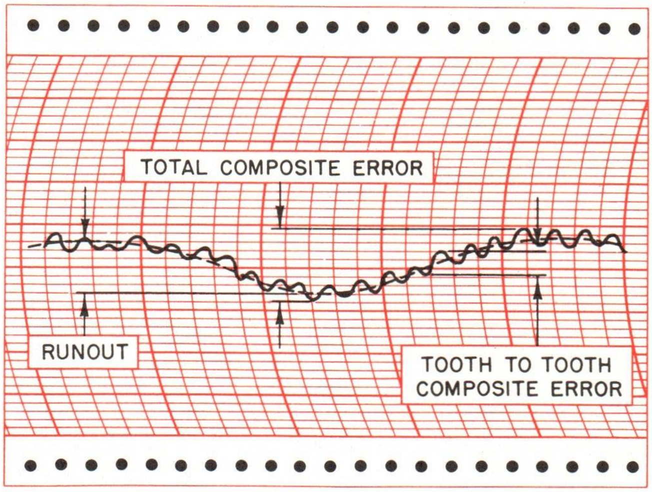


Figure 7. Chart produced by gear rolling.

Figure 6. Production check - gear mounted between centers.

blanks, heat treatment and all other operations. *A closer study of gear errors and their origin reveals the plain fact that the majority are caused by failure to control runout somewhere.*

Manufacturers of hobbing and shaping machines will readily point out that true running tool and work spindles and index and index worm gears, more than anything else, determine the accuracy of their machines. Makers of hobs state that "weave" determines hob quality more than any other tolerance. "Weave" is the repetitive lead variation in every convolution of hob teeth and is caused by runout. The sharpening errors on hobs are not so much due to sudden spacing errors between flutes as to accumulations due to poor arbors or eccentricity in the head stock spindles and index plates.

The problem of runout enters even into master gears whose tolerances on involute, spacing and lead are small compared to those for runout. Therefore, it is no exaggeration to say that the constant *control of runout* at all phases of gear manufacturing, more than anything else, determines the quality of the gears.

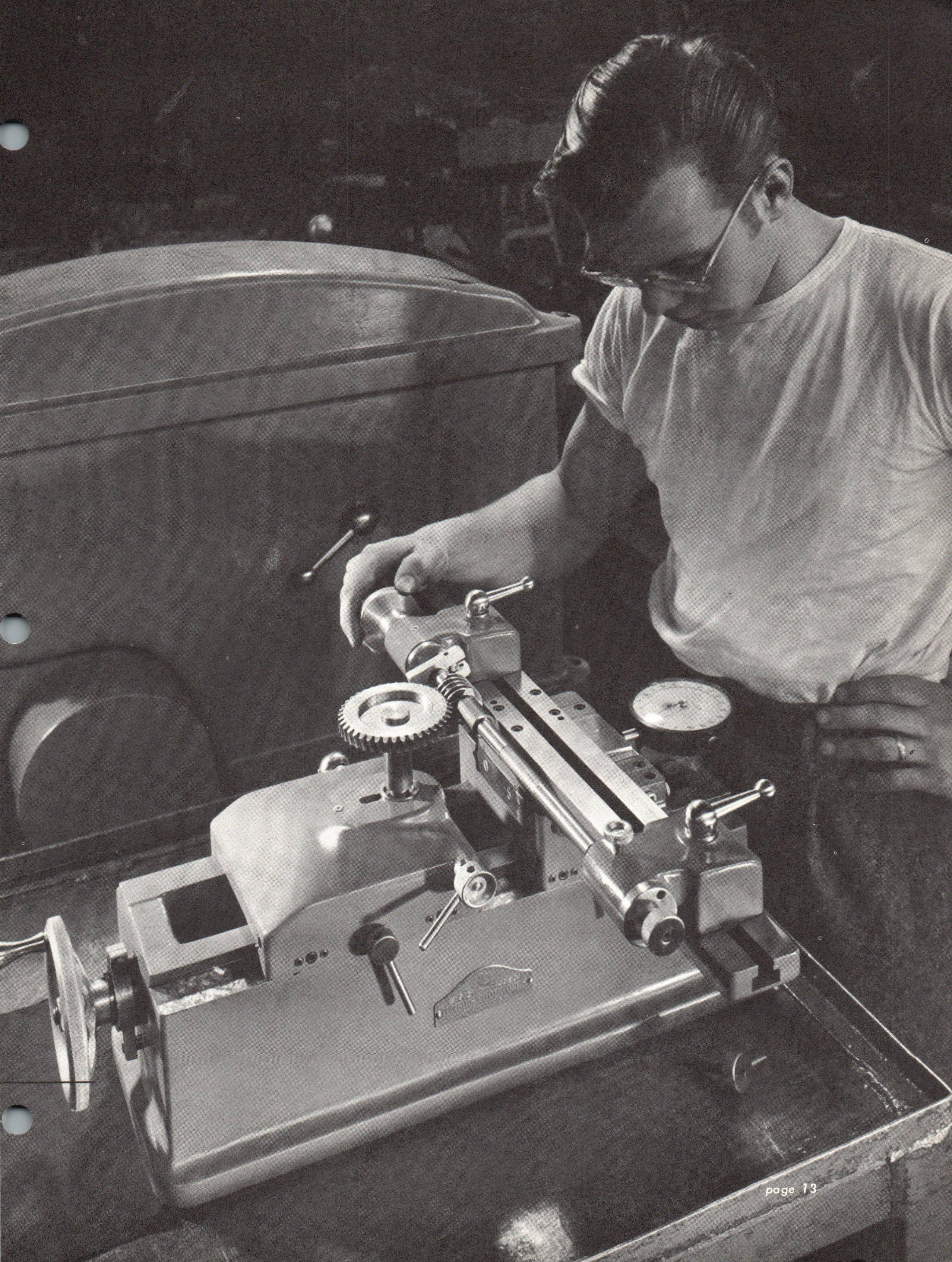
Poor holes in gear blanks, side wobble, runout in work spindles and checking arbors, eccentricity of the index gears of hobbing and shaping machines —all these do but one thing, produce a runout in the gear. The same goes for runout in a shaper cutter, which produces irregularities of concentricity, combined with one large spacing error. All these runout errors are readily detected in gear rolling because they are reflected in center distance variation *at their true value.*

On the other hand, runout in a hob or the hob spindle, faulty hob sharpening and errors in the shape of the hob, shaper cutter or shaving cutter teeth can only affect the *shape* of the individual gear teeth. Such errors will be reflected at a distorted or magnified ratio as a tooth-to-tooth flicker of the indicator or recording pen. This "roughness" of rolling indicates that the *normal* spacing of the gear teeth is not uniform for every degree of rotation, but it does not tell whether only one or both sides of the involute are responsible or whether it is the fault of the involute or the spacing. As a rule, the tooth-to-tooth flicker is an involute error which repeats itself with amazing uniformity on every tooth.

Heat treatment may affect both the shape and the concentricity of gear teeth. In the latter case it is not so much a question of runout as of egg shape or other form of out-of-roundness.

If functional gear checking is combined with recording it becomes readily possible to separate the tooth-to-tooth errors from those which have affected the concentricity of the gear teeth. As previously mentioned, the lack of concentricity is reflected at its true value. The tooth-to-tooth flicker, even though it represents a composite of errors of a distorted value, can be assigned a tolerance. Recording, therefore, refines the functional check and permits an insight into the character of the errors which is not obtainable with plain indicators. Furthermore, recording makes it much easier to show up the effects of heat treatment of finishing operations. Graphs made before and after may be

Figure 8. Illinois Tool Works worm gear rolling fixture.



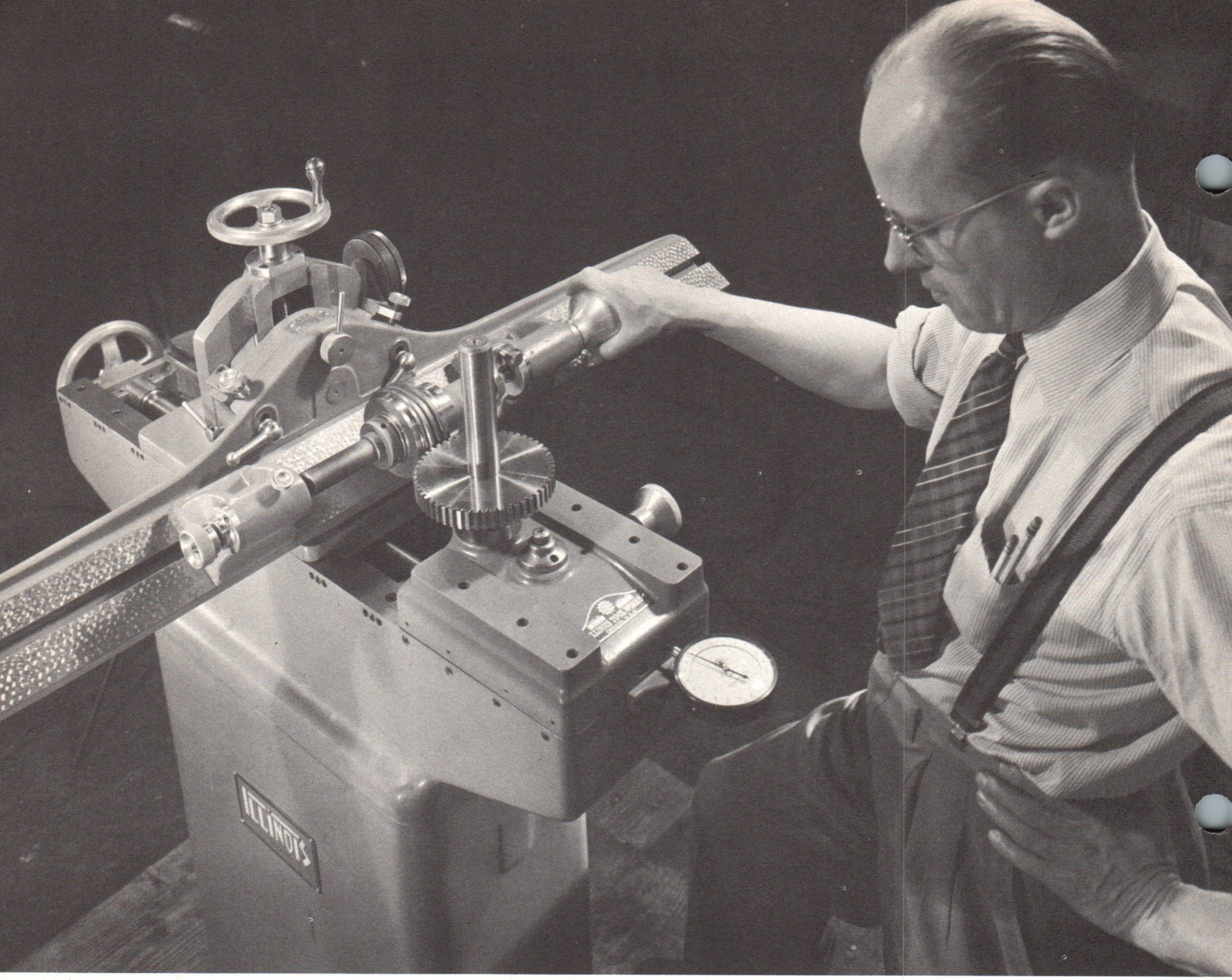


Figure 9. Runout and size checking.

directly compared (see Illinois Tool Works booklet on "Graphic Inspection").

In general, these are the advantages of combining recording or *graphic* inspection with functional gear checking:

1. Recording gives a breakdown between tooth-to-tooth errors and those of concentricity.
2. In distinguishing between these errors, it furnishes clues to their sources and therefore is indispensable in maintaining a high degree of accuracy.
3. Charts are more easy to read and give permanent inspection records. Charts of the same gear at various stages of its manufacturing cycle may be directly compared.

SUMMARY

Gear rolling fixtures, using master gears and indicators, are placed directly among hobbing, shaping and shaving machines to check constantly the output of these machines. They are also placed in the final inspection department—sometimes combined with recording. As more elaborate universal machines, always combined with recordings, they are an important part of every gear laboratory.

The functional gear checking fixtures are the policemen of the gear manufacturing process. The involute, space and helical lead checking fixtures are the judges.

Functional gear checking gives a true measurement of size and runout. Beyond that it gives an admittedly distorted but nevertheless indicative picture of the individual tooth errors.

The addition of recording makes it possible to distinguish better between the individual tooth errors and those of size and concentricity. It furnishes clues to the source of errors and is indispensable in maintaining a high degree of accuracy.

A complete line of specially designed equipment has been developed by Illinois Tool Works for both functional and analytical gear checking.

1

FUNCTIONAL GEAR MEASURING MACHINES

Parallel Axis Gear Rolling Machine, 12″ Center Distance Capacity
Parallel Axis Gear Rolling Machine, 20″ Center Distance Capacity
Bevel Gear Rolling Machine
Worm and Worm Gear Rolling Machine
Internal Gear Rolling Machine
Spur and Helical Gear Charter
Bevel and Hypoid Gear Charter

2

ANALYTICAL GEAR MEASURING MACHINES

Involute Profile Measuring Machine
Tooth Spacing Comparator
Helical Lead Measuring Machine

3

HOB AND WORM MEASURING MACHINES

Hob and Cutter Sharpening Checker
Hob Contour Measuring Machine
Variable Hob and Worm Lead Measuring Machine
Universal Hob and Worm Measuring Machine

4

RECORDING EQUIPMENT

For Analytical Gear Measuring Machines
For Hob and Worm Measuring Machines

"Headquarters for Engineered Cutting Tools"

Hobs • Broaches • Shaper Cutters • Milling Cutters
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